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Breaking geographic and language barriers in neuropsychology: online administration of MoCA in diverse populations

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Traditional in-person neuropsychological tests remain inaccessible and not adapted to individuals in remote geographical locations and linguistically diverse populations. We aimed to make neuropsychological tests more accessible and adapted to diverse populations by leveraging the internet. We examined the feasibility, discriminability, and generalizability of the Montreal Cognitive Assessment-video conferencing version (MoCA-VC) across geographically and linguistically diverse populations. We tested 250 participants from 120+ locations in the USA and Israel, using a standardized MoCA-VC protocol in English, Hebrew, or Arabic. Performance followed expected significant trends across language-speaking cohorts: young adults (YA)>older adults (OA)>people with Parkinson's Disease (PwP), confirming discriminative abilities. However, while the YA groups performed similarly across the three language-speaking cohorts, the OA and PwP Arabic-speaking cohorts demonstrated significantly lower scores, indicating limited generalizability. While these findings support MoCA-VC's feasibility and discriminability, they underscore the need to adapt online cognitive assessments across geographical locations and languages, ensuring greater accessibility worldwide.

Neuropsychological evaluation is an essential tool for assessing cognitive function, worldwide[1–9]. Neuropsychological research has long contributed to understanding cognitive processes and brain functionality across various languages and countries[1–10]. Over the past centuries, societies have become increasingly diverse. This trend is partly driven by advances in technology and the widespread availability of affordable transportation, which have facilitated increased global mobility[11]. Individuals travel more frequently across geographical and cultural borders, acquiring new languages and adapting to local norms[11]. Israel serves as a pertinent example. Immigration from the former Soviet Union, North Africa, and Western countries has resulted in a diverse multilingual and multicultural population. While Hebrew remains the official language, it is continuously shaped by the incorporation of foreign vocabulary, syntactic structures, and phonetic patterns[12]. This linguistic complexity poses challenges for standardized cognitive assessment[13]. For instance, individuals from Arabic-speaking backgrounds or recent immigrants may encounter difficulties when evaluated with tools developed and normed for native Hebrew speakers. Such limitations should prompt efforts to develop assessment strategies that account for linguistic or cultural diversity. Thus, as demographic diversity increases, it becomes imperative to align cognitive assessment frameworks with the realities of multilingual and multicultural populations[11].

However, the accessibility and validity of neuropsychological tests is often limited by geographic and linguistic boundaries. These constraints disproportionately affect diverse populations, such as those residing in remote locations, limiting equitable access to cognitive evaluations. As digital technologies advance, the online administration of neuropsychological tests offers a promising solution to bridge these gaps, facilitating evaluation across diverse populations.

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In today's increasingly dynamic and globalized world, geographic barriers and language differences can impact the reliability and validity of neuropsychological tests[2,5,6,14]. Cognitive evaluations need to be adapted to each specific community to ensure that tests are not only equally accessible, but also valid per the true and specific abilities of each community[2,14–17]. These community-specific adaptations are especially critical for minority groups and non-English-speaking populations, where linguistic and geographical barriers often amplify existing disparities in healthcare[5,18].

Community-specific adaptations refer to the modifications necessary to ensure that cognitive assessments are culturally and linguistically appropriate for diverse populations[2,14–17]. These adaptations are critical to maintaining the validity and reliability of the test across three key stages: development, administration, and scoring[2,3,19–21].

In test development, adaptations may include linguistic translation and cultural modification of test content. For example, when adapting word-list memory tasks, culturally unfamiliar items may be replaced with equivalent words relevant and frequent in the target population. Visual stimuli, like animals or objects, may also be altered to align with regional familiarity. For example, when developing a test, one should consider if certain visual images used in a Western neuropsychological test are culturally-relevant to a community in Africa, especially given that cognitive constructs may differ in non-Western civilizations[21]. During test administration, adaptations may involve the recruitment of bilingual examiners or matching the examiners-examinee according to language and culture, providing instructions in multiple languages, or adjusting communication style to fit socio-cultural norms. In addition, administrators should be familiar with and aware of a participant's specific cultural background. Administrators may have a biased judgment of a participant if they are not aware of behavioral or linguistic mannerisms specific to a culture. This judgment can both influence participants' experience and performance during a task and the administrator's scoring[19]. Similarly, in test scoring, adaptations may include adjusting normative data based on the specific language and cultural background of the examinee or allowing for culturally appropriate variations in responses, ensuring cultural sensitivity in scoring. For instance, a sentence or narrative recall that follows culturally specific storytelling patterns may still be considered accurate within the examinee context. These adaptations ensure fairness and diagnostic accuracy in cognitive testing across multilingual and multicultural populations.

Previous neuropsychological studies have often relied on samples that lack geographic diversity[4,5]. In many cases, these studies draw participants predominantly from a single area, often metropolitan cities with access to medical centers[4,5,22]. This narrow geographical focus limits the generalizability of neuropsychological tests and their administration to broader populations, particularly those in rural or underserved regions. Additionally, many studies in the field of cognitive science rely heavily on English-speakers[23]. The over-reliance on English-speaking participants, and often English-speaking researchers as well, can introduce a bias in the measurement of cognitive functions, potentially hindering cognitive assessments[23]. Most cognitive tests are developed, normed, and validated using monolingual English speakers, often from Western cultures[24–27]. This can result in construct bias, where tasks do not measure the same cognitive constructs across languages. For instance, verbal fluency tasks based on English phonemes or semantic associations may disadvantage speakers of languages with different phonological or lexical structures. Semantic groupings that are culturally relevant for one group may not apply to another[28]. Similarly, memory tasks relying on culturally familiar word lists may fail to reflect the cognitive abilities of non-English speakers due to cultural misalignment[13,21,29].

As previously discussed, tests translated into other languages often lack rigorous linguistic and cultural adaptation, making it unclear whether poor performance reflects cognitive impairment or limitations of translation. Furthermore, normative bias occurs when results are interpreted using norms developed from English-speaking populations. This can lead to misclassification, such as over or under diagnosing cognitive impairment in older adults from non-English-speaking backgrounds, particularly when cultural variables are not accounted for (e.g., the detrimental gap in our ability to detect dementia in non-English speakers.)[30]

Historically, the Sapir–Whorf Hypothesis supports the idea that language shapes cognitive processing[31]. That is, if cognitive assessments are designed around English language structures and administered or scored in English, they may fail to capture the cognitive profiles of individuals of different native language structure[31]. A growing body of research[13,19,21,23,29] suggests that the dominance of English in cognitive testing leads to the overgeneralization of cognitive norms based on English speakers, effectively excluding the cognitive variability of speakers of other languages. This creates a systematic gap in neuropsychological research and practice, reinforcing health disparities and reducing diagnostic accuracy for large segments of the global population[30]. By recruiting participants from diverse geographical locations who speak different languages, we aimed to have a better representation of the general population and emphasize the need for more inclusive and diverse study populations.

To address these challenges, we investigated the feasibility, discriminative abilities, and generalizability of the videoconferencing version of the Montreal Cognitive Assessment, MoCA-VC[32], by administering it to geographically and linguistically diverse populations. We have utilized the MoCA[32], a globally recognized cognitive screening tool used to assess mild cognitive impairment (MCI). The MoCA is a brief, 10-minute screening tool that evaluates eight cognitive areas: visuospatial abilities, naming, memory, attention, language, abstraction, delayed recall, and orientation[32]. It has demonstrated strong validity and reliability across clinical groups[33,34], with a sensitivity of 86% and specificity of 88% for detecting MCI[33]. Additionally, the MoCA is particularly sensitive to cognitive changes associated with Parkinson's disease, with diagnostic metrics surpassing those of traditional tools such as the Mini-Mental State Examination (MMSE)[35].

One promising administration method is the videoconferencing version of the MoCA (MoCA-VC), which has been demonstrated as a feasible and valid remote tool[2–4,10,36–38]. Feasibility refers to the level of ease in which a test can be utilized in a given context, such as participant completion rate. A high completion rate demonstrated the feasibility of the MoCA-VC, as 100% of the participants who started the test also completed the test, including individuals with movement disorders[39]. Regarding validity (how accurately a test measures the construct it aims to assess), previous studies have demonstrated convergent validity by comparing the MoCA-VC to the in-person test, and have shown the test's ability to discriminate between groups. For example, studies have shown no significant differences in test scores between the MoCA-VC and the standard in-person MoCA when administered to both healthy and patient groups[2,4,10]. In clinical populations —such as individuals with cerebellar ataxia, who are expected to exhibit cognitive deficits on the MoCA—similar impairments were observed when using the MoCA-VC, supporting its clinical sensitivity[2,10,39]. Remote assessments like the MoCA-VC address the key challenges of accessibility and inclusivity in traditional in-person testing, benefiting both neurotypical healthy (NH) individuals and those with clinical conditions, such as people with Parkinson's disease (PwP)[2].

While studies have demonstrated the validity of the MoCA-VC in English[4,40], only a few have done so in other languages. A recent study compared MoCA scores obtained face-to-face (F2F) with those obtained via MoCA-VC in a large sample ($n = 491$) of healthy English-speaking participants[4]. The study found no differences between the two methods, supporting the validity of MoCA-VC. Another study administered the MoCA-VC to English-speaking patients with mild-to-severe dementia and found an excellent intra-class coefficient reliability ($ICC = 0.93$)[40]. In contrast, a study amongst Japanese-speaking cohorts found that the ICC for the MoCA-VC was high overall but varied depending on the participant subgroup. The ICCs were lower in healthy controls (0.53) compared to those with MCI (0.82) or dementia (0.82)[41]. Given these studies, it remains unclear whether MoCA-VC is valid and generalizable in geographically and linguistically diverse clinical populations.

Few studies have demonstrated the feasibility and efficiency of administering the MoCA-VC in PwP. Since PD is the most common motor neurodegenerative disease, studying this group enhances the possible generalizability of our findings to more clinical populations. Given the significant motor impairments typical of PD, successful remote administration of the MoCA-VC in this group offers strong support for its clinical utility under motor-challenging conditions. Choosing a population without motor symptoms, such as Alzheimer's disease, would assess feasibility under potentially more favorable motoric disease conditions and thus provide less stringent evidence for the feasibility of the remote approach. Additionally, PD is a progressive neurodegenerative disorder frequently associated with MCI and dementia[42,43]. Early identification of cognitive decline is essential for treatment planning, yet many individuals with PD lack access to in-person neuropsychological assessment. However, the cognitive demands of the test may prove more challenging for individuals with Alzheimer's disease, and therefore, future work on this population is warranted[23,32].

One study utilizing a small sample (n = 8) of English-speaking PwP showed the feasibility of the MoCA-VC for PwP. Feasibility was demonstrated by successfully collecting data from PwP living in several geographical locations within the USA. The high completion rate (100%) of the online test indicates that participants were able to easily access and complete the assessment remotely, supporting the practicality and user-friendliness of the online format[39]. However, this study did not compare the VC to F2F scores[39]. In a pilot study, utilizing a small sample (n = 11) of English-speaking PwP, participants completed the F2F MoCA followed by the MoCA-VC a week later[44]. No differences were found between the two administration methods. However, due to the small sample size, the validity of the MoCA-VC among these patients is poorly understood. While there is one study that utilizes a large database (n = 166) of PwP[45], no comparison was made between the patients and NH participants. Lastly, most of the studies that administered MoCA-VC to both NH and PwP recruited English-speaking cohorts[2,46]. Thus, whether MoCA-VC is valid and generalizable among non-English speakers for both NH and PwP is yet to be determined.

As an initial step to address these gaps, we examined the feasibility, discriminative abilities, and generalizability of administering the MoCA-VC amongst diverse populations. We enrolled participants from more than 120 geographical locations across two countries: USA and Israel. These two countries have strikingly culturally and linguistically diverse populations. Over the past century, people from Africa, East Asia, Europe, and more have immigrated to the USA and Israel. Thus, neuropsychologists encounter diverse individuals in clinical practice[11]. However, as previously stated, without proper adaption to specific cultural and linguistic contexts, this diversity can significantly impact neuropsychological administration and scoring processes[5,6]. Thus, the assessments need to be adapted to suit these diverse populations, an internationally recognized need[47].

Using a standardized administration MoCA-VC protocol, we tested 250 participants from three language-speaking cohorts: English, Hebrew, and Arabic. Within each language-speaking cohort, we included three different participant groups: young adults (YA), older adults (OA), and PwP. By doing so, we aimed to assess the discriminative abilities of the MoCA-VC by comparing the three participant groups (YA vs. OA vs. PwP), which typically differ in MoCA scores. Within each language version, based on previous in-person studies[2,3], we expected the YA to score higher than OA, and the OA higher than the age-matched PwP. In addition, we aimed to examine the generalizability of the MoCA-VC by testing the equivalence of three language versions of the MoCA-VC (Hebrew vs. English vs. Arabic) in each participant group. If all language versions of the MoCA-VC are appropriately suited to each participant group, no differences between the three languages should be found. However, if differences between the language versions are found, they may indicate important factors that can significantly impact the test's generalizability.

Results

Convergent validity and reliability

First, for confirmation, we evaluated the convergent validity of the MoCA-VC among the healthy English-speaking cohorts. Previous studies have already demonstrated the convergent validity of MoCA-VC among healthy English-speaking cohorts[2,4,10]. In line with these recent papers, our samples' average MoCA-VC scores for both healthy English-speaking cohorts were within the normal range (> 26; YA = 27.8, OA = 26.5). In addition, we compared our online results with the norms published in the original study in OA[32] that administered the MoCA through the traditional in-person method. We found no significant difference between our sample and the previously published norms [$\mu = 27.4$; $t(29) = 1.317$, $p = 0.198$, effect size = 0.240; See Fig. 1], further confirming the convergent validity of MoCA-VC among healthy English-speakers. We also compared the Hebrew and Arabic versions of the MoCA-VC to language-matched published norms from prior studies[48,49] and no significant differences were found (Hebrew: $t(29) = 2.0$, $p = 0.055$, effect size = 0.37; Arabic: $t(29) = 0.00$, $p = 1.0$, effect size = 0.00).

To further examine the reliability of the MoCA-VC, we calculated internal consistency using Cronbach's alpha for each language version.

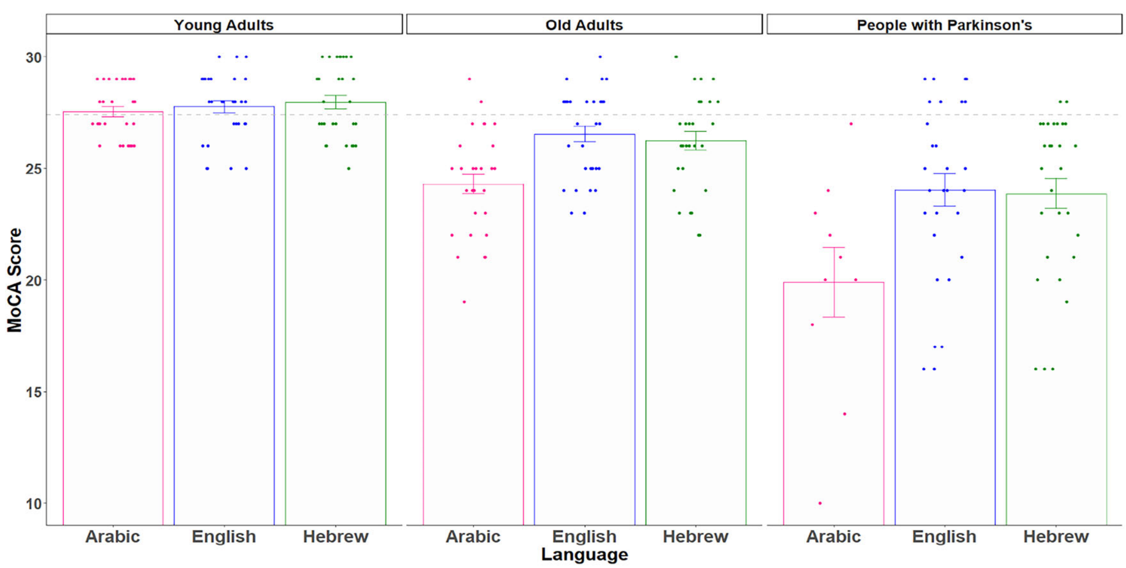

Fig. 1 | MoCA-VC scores by group and language. Bar plots of MoCA-VC scores for each participant across the three groups: Young Adults, Older Adults, and People with Parkinson's Disease, and three languages: Arabic, English, and Hebrew. Each dot represents an individual score. The horizontal dotted line represents the literature-derived threshold for healthy controls. Pink bars indicate the Arabic-speaking cohort, blue bars indicate English-speaking cohort, and green bars indicate the Hebrew-speaking cohort. Error bars reflect the standard error of the mean (SE).

Results demonstrated acceptable internal consistency across all three languages: Hebrew ($\alpha = 0.78$), Arabic ($\alpha = 0.81$), and English ($\alpha = 0.80$). These results provide supporting evidence that the MoCA-VC yields consistent results across languages in our multilingual sample.

Discriminative abilities & generalizability

Given that the effects of age (e.g., YA vs. OA) and education (i.e., <12) on the MoCA score are well established, these variables were included as covariates in subsequent analyses to account for their potential confounding effects. We conducted an analysis of covariance (ANCOVA) to examine the effects of Group, Language, and their interaction on MoCA-VC scores while controlling for age and years of education. As expected, age ($F(1, 209) = 10.65$, $p = 0.001$) and years of education ($F(1, 209) = 4.85$, $p = 0.029$) were both significant covariates, with older age and fewer years of education associated with lower MoCA scores.

Importantly, this analysis revealed that even when age and years of education were controlled as covariates, there are significant main effects of Group ($F(2, 209) = 58.98$, $p < .001$) and Language ($F(2, 209) = 10.67$, $p < 0.001$), indicating that both factors independently influenced cognitive performance. There was also a significant interaction between Group and Language ($F(4, 209) = 5.11$, $p < 0.001$), suggesting that the effect of Language on MoCA scores varied across participant groups. This significant interaction between Group and Language points towards the limited generalizability of MoCA-VC across the three languages. See Fig. 1 for the MoCA-VC score as a function of Group and Language.

To further understand this two-way interaction, we utilize planned comparison analysis at each Language level. First, as expected from previous studies[17,50] we found significant differences within the English-speaking cohort. The comparison between YA and OA was significant ($t(58) = 2.705$, $p = 0.008$, Cohen's $d = 0.698$), with lower scores for the OA. The comparison between OA and PwP was also significant ($t(58) = 3.082$, $p = 0.0031$, Cohen's $d = 0.796$), with lower scores for the PwP. These results provide evidence for the MoCA-VC's discriminative ability among English speakers. Second, we examined the group differences among the Hebrew-speaking cohort. The comparison between YA and OA was significant ($t(58) = 3.413$, $p = 0.0012$, Cohen's $d = 0.881$), with lower scores for the OA. The comparison between OA and PwP was also significant ($t(58) = 2.985$, $p = 0.0041$, Cohen's $d = 0.771$), with lower scores for the PwP. This pattern of results provides further evidence for the MoCA-VC's discriminative ability among Hebrew speakers. Third, we examined the group differences among the Arabic-speaking cohort. The comparison between YA and OA was significant ($t(58) = 6.648$, $p < 0.0001$, Cohen's $d = 1.717$), with lower scores for the OA group. The comparison between OA and PwP was also significant ($t(38) = 3.815$, $p = 0.0004$, Cohen's $d = 1.393$), with lower scores for the PwP group. These results similarly support the MoCA-VC's discriminative ability among Arabic speakers. See Fig. 1.

Importantly, to examine the effect of Language on cognitive performance within each participant group, we conducted pairwise comparisons of estimated marginal means (EMMs) of MoCA-VC scores while controlling for age and years of education. Among YA, no significant differences in MoCA-VC scores were found across languages (all p-values > .250). These findings suggest that the different language versions did not significantly impact the scores in the MoCA-VC within YA.

However, when comparing the OA across the three language-speaking cohorts, we observed significant differences in MoCA-VC scores. The Arabic-speaking cohort scored significantly lower than both English speakers ($t(209) = -2.46$, $p = 0.044$) and Hebrew speakers ($t(209) = -2.98$, $p = 0.0098$), with no significant difference between English and Hebrew speakers ($t(209) = -0.13$, $p > 0.250$). These results suggest that language modulated MoCA-VC score among the OA group, particularly for Arabic-speaking participants who consistently scored lower than the English and Hebrew-speaking participants.

Similarly to the OA group, we found significant differences when comparing the PwP group across the three language-speaking cohorts. Following a similar pattern, the Arabic-speaking cohort scored significantly lower than both English ($t(209) = -5.06$, $p < 0.0001$) and Hebrew-speaking cohorts ($t(209) = -5.18$, $p < 0.0001$). There was no significant difference between the English and Hebrew-speaking cohorts ($t(209) = 0.91$, $p > 0.250$). These results indicate that language-related changes in cognitive performance are present in the older adults and the PwP groups, particularly among Arabic speakers, even after adjusting for potential effects of age and years of education.

Overall, we found lower scores in OA compared to YA, and lower scores in PwP compared to OA. These between-group differences within each language-speaking cohort provide evidence for the MoCA-VC's discriminative abilities in all three languages. When examining the effect of language on each participant group, no differences were found between the three language-speaking cohorts in YA. However, among OA and PwP, we found that the Arabic-speaking cohorts scored lower than the English- and Hebrew-speaking cohorts. This finding suggests that while MoCA-VC is generalizable across English and Hebrew, the Arabic version is only generalizable to YA, but not to OA and PwP.

To further assess our finding of the MoCA-VC's discriminative abilities, we also examined the percentage of participants who received a score below 26 in each group. See Fig. 2 for the histograms of the MoCA-VC score as a function of participant group and language. The dashed vertical line marks scores of 26, indicating the criterion of MCI. Aligned with previous literature[2,10], only 5% of YA received a score below this criterion. Additionally, 47% of the OA group and 61% of PwP group received below this criterion of MCI, further supporting the discriminative ability of the MoCA-VC among these participant groups.

Given the previous discrepancy found among OA and PwP, we then focused on these groups, revealing a striking effect of language. Among these groups, differences emerged in the proportion scoring below the MCI threshold of 26. In the Hebrew-speaking cohort, 40% of participants fell below this criterion, and in the English-speaking cohort, this proportion was 50%. However, the disparity was most pronounced in the Arabic-speaking cohort, where a staggering 78% of participants scored below the MCI criterion.

Discussion

We evaluated the MoCA-VC's feasibility, discriminability, and generalizability across three participant groups (YA, OA, PwP) and three language-speaking cohorts (English, Hebrew, Arabic). The 250 participants were from 126 different geographical locations in two countries: USA and Israel. Across all language-speaking cohorts, we found that the YA group scored higher than the OA group, and the OA group scored higher than the PwP group. This between-groups pattern of results aligns with previous findings[2,3,10,46].

We next compared the three language-speaking cohorts in each participant group. Interestingly, the Arabic-speaking OA and PwP scored lower on the MoCA-VC than their Hebrew- and English-speaking counterparts. However, among the YA group, we did not find differences between the three language-speaking cohorts.

We have identified three main potential reasons why Arabic-speaking OA and PwP scored lower compared to the English and Hebrew speakers. First, the Arabic version of the MoCA may not be fully adapted to the Arabic-speaking population in Israel. Arabic speakers in Israel are often bilingual (speaking both Arabic and Hebrew), resulting in different interpretations of the MoCA Arabic version instructions. Specifically, in the TMT test, where participants are asked to connect letters and numbers in ascending order, while the letters are presented in Arabic, participants often reported they interpreted them according to the Hebrew letter sequence, leading to incorrect answers. Participants identified the letter “ج“ (IPA: /d͡ʒiːm/) equivalent to “G” in Hebrew after the number three, even though the instructions ended with the letter “ج“ marked with “End.” We believe this confusion arises from the Hebrew letter sequence (“א-ב-ג-ד-ה“; IPA: /ʔalef, bet, gimel, dalet, he/) versus the Arabic sequence (“أ-ب-ت-ث-ج“; IPA: /ʔalif, baː, taː, θaː, d͡ʒiːm/). In Arabic, “ج“ is the fifth letter, while in Hebrew, it is the third. To address this gap, before starting this study we changed the

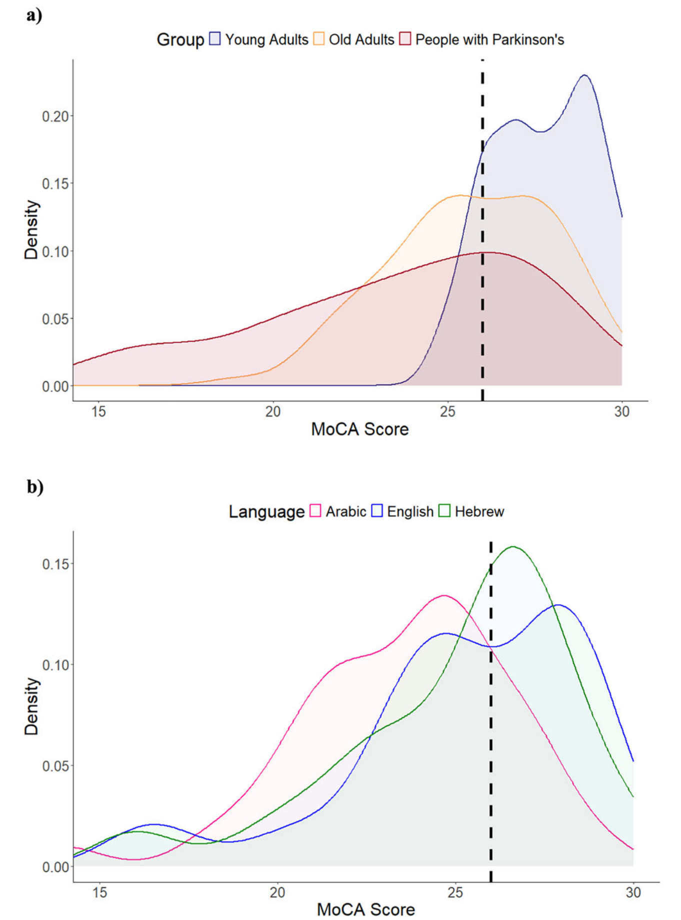

Fig. 2 | Distributions of MoCA-VC scores. a Density plots of MoCA-VC scores for Young Adults (blue), Older Adults (orange), and People with Parkinson's Disease (dark red). The vertical dashed line indicates the clinical cutoff score of 26 for mild cognitive impairment. Among Young Adults, 5% scored below this threshold; among Older Adults, 47%; and among PwP, 61%. Shaded areas represent density distributions. **b** Density plots of MoCA-VC scores across language cohorts in Older Adults and PwP: Arabic-speaking cohort (pink), English-speaking cohort (blue), and Hebrew-speaking cohort (green) participants. The cutoff of 26 is indicated by a vertical dashed line. While 40% of Hebrew speakers and 50% of English speakers scored below 26, 78% of Arabic speakers fell below this criterion. Shaded areas represent density distributions.

instructions to: "قم بالإجابة حسب ترتيب الحروف الأبجدية العربية وليس حسب الحروف العبرية" (IPA: /qum biʔilʔiːd͡ʒaːba ħasaba tartiːb alħuˈruːf alʔabd͡ʒadiyyah alʕarabijjah waˈlajsa ħasaba alħuˈruːf alʕibrijjah/; Arabic for "Answer according to the Arabic alphabetical order, not the Hebrew one"). Thus, this change could not fully explain the lower results among the OA and PwP Arabic-speaking cohorts. We recommend modifying the TMT's instructions to suit the linguistic characteristics of the Arabic-speaking population in Israel. Notably, our recommendation applies to both the online and F2F versions of the MoCA.

Correspondingly, the Arabic MoCA appears to be also unsuitable for Arab-speaking populations in Israel given the nuances of Arabic dialects between different cities and villages (and countries). In the MoCA's Language test, participants are required to repeat sentences, one of which includes the word "هر" (IPA: /hir/; Arabic for "cat"). However, the term "هر," is less commonly used by Arabic speakers in Israel compared to other words such as "قط"' (IPA: /qitˤ/) or "بِس" (IPA: /bɪs/), creating difficulty or confusion for participants. Therefore, we recommend adapting this item to the population living in Israel by implementing the more commonly used term for "cat": "قط.". Unfortunately, we identified this potential improvement after completing the current study, so we did not adapt the test's instructions accordingly. This community-specific linguistic difference hinders accurate testing if not taken into account, potentially leading to underestimation (lower scores) of OA and PwP Arabic-speaking populations. We recommend modifying this language item to better suit the linguistic context of the Arabic-speaking population in Israel. Importantly, again, our recommendations apply to both the online and F2F versions of the MoCA.

The second factor that may have impacted the scores of the OA and PwP Arabic-speaking cohorts is limited access to technology and digital proficiency. Given that Arabic-speaking OA and PwP living in Israel typically live in villages with limited access to the internet or reduced exposure to technology (e.g., platforms such as Zoom), these technological challenges are more pronounced within their communities[51]. Thus, OA and PwP Arabic-speakers in Israel can benefit from training and support before conducting the actual assessment.

The third factor possibly contributing to Arabic-speaking OA and PwP lower performance is their fewer years of education, with a mean of 13.3 years for OA and 11.8 years for PwP (see Table 1). Previous studies have demonstrated that education level can have a significant impact on MoCA performance, with people of lower levels of education scoring lower than those with high levels of education[17,52]. It is possible that Arabic-speaking populations have lower levels of education compared to other populations living in Israel and that these differences may be impacting their performance. However, we were not able to find studies supporting this hypothesis, and our ANCOVA analysis suggests that these group differences are not fully explained by years of education. Thus, it remains to be determined if our sample is biased or truly represents the population. To disentangle these potential three factors contributing to the lower scores of Arabic-speaking OA and PwP, we recommend future studies investigate these factors in an orthogonal manner.

In relation to these factors, there are two primary limitations to our study. First, while our total sample size was 250, our sample size for Arabic-speaking PwP was limited (n = 10) compared to English and Hebrew-speaking PwP (n = 30/group). We faced significant challenges in recruiting Arabic-speaking PwP in Israel potentially due to testing stigma. As reported by our participants and supported by several studies[53–55], there is a stigma in seeking in-person testing and participating in social activities in the Arab PwP community in Israel. Furthermore, this stigma not only affects healthcare access but also perpetuates underdiagnosis and undertreatment of cognitive impairments within the Arabic-speaking community, further compromising individuals' well-being. Additionally, the limited access to technology and digital proficiency mentioned earlier may hinder Arabic-speaking individuals from learning about our study through online resources. We hope to implement and encourage more community-based awareness and interventions within these populations.

Second, we measured the convergent validity of the MoCA-VC by comparing our scores to data from traditional in-person testing obtained in previous studies. A stronger measure could have been obtained through a direct comparison: having each participant complete both administration methods (VC and in-person) in counterbalanced, random order. However, this was not possible given that we collected data from 250 participants, who reside in more than 120 different geographical locations, in two countries. Notably, several previous studies have demonstrated the validity of the MoCA-VC[2,4,10]. Thus, we have chosen to focus on a diverse sample from different geographical locations. We acknowledge that the absence of the within-sample validation is a limitation. Without access to within-participant data, we cannot determine whether the results are due to population differences or to methodological differences (e.g., modifications or mode of administration). As such, these findings must be interpreted with caution. Future work should include within-sample validation to support the equivalence of the MoCA-VC version[2,4,10].

We collected data from participants located in over 120 distinct geographic locations across two countries, demonstrating real-world feasibility. However, we also acknowledge the absence of other direct feasibility metrics. We recommend that future studies incorporate completion rates and

Table 1 | Demographic and medical information of all groups. Mean [SE]

Group	Language	N	Age	Years of education	MoCA	MDS-UPDRS III	Disease duration
YA	Arabic	30	23.3 [0.6]	14.7 [0.3]	27.5 [0.2]	NA	NA
YA	English	30	22.4 [0.4]	14.6 [0.3]	27.8 [0.3]	NA	NA
YA	Hebrew	30	25 [0.6]	14.5 [0.4]	28 [0.3]	NA	NA
OA	Arabic	30	62.5 [1.1]	13.3 [0.5]	24.3 [0.4]	NA	NA
OA	English	30	62.3 [1.5]	14.5 [0.5]	26.5 [0.4]	NA	NA
OA	Hebrew	30	62.9 [2]	14.6 [0.4]	26.2 [0.4]	NA	NA
PwP	Arabic	10	51.5 [4.5]	11.8 [1.2]	19.9 [1.6]	22.4 [3.1]	6.1 [1.7]
PwP	English	30	66.6 [1.7]	15.6 [0.4]	24 [0.7]	21.4 [2.0]	6.4 [1.1]
PwP	Hebrew	30	64.6 [1.7]	15.1 [0.4]	23.9 [0.7]	22.2 [2.4]	5.8 [0.8]

MoCA Montreal Cognitive Assessment, *MDS-UPDRS* Movement Disorder Society–Unified Parkinson's Disease Rating Scale, *YA* young adults, *OA* older adults, *PwP* people with Parkinson's.

structured questionnaires that allow participants to report their technical experience and overall usability of the online test.

To conclude, neuropsychological testing often requires traveling to medical centers, which are commonly located in metropolitan areas, leading to low diversity and lack of representation. In addition, the tests are not always adapted to all language speakers. To address these limitations, in the last decade, the utilization of remote testing platforms has demonstrated promising results mainly regarding the feasibility and efficiency of collecting neuropsychological data online. Given our results, future studies can utilize the MoCA-VC, but carefully adapt it to each specific community and language speaker. Remote neuropsychological administration shows promise for allowing more accessible, efficient, and accurate cognitive assessments across various patient populations, language versions, and nations[2].

Methods

Power Analysis

To calculate the required sample sizes, we conducted a power analysis ($\alpha = 0.05$; power = 0.90) using effect sizes derived from studies that compared PwP and a neurotypical group in the MoCA-VC test[2,22,46]. These analyses suggested a minimal sample size of 21 participants per group. As such, the sample sizes of our groups ($n > 29$) had sufficient power to detect group differences for most comparisons (except for the PwP Arabic speakers). This adjustment accounts for the increased variability associated with remote administration, including differences in test conditions. By aligning our effect size estimates with prior MoCA-VC research, we improve the validity of our statistical assumptions and ensure that our power analysis more accurately reflects the conditions of the current study.

To our knowledge, no previous studies compared these three participant groups across three different languages of the MoCA. Given uncertainties about data quality with this novel online approach, we set a larger target for this VC study of 30 individuals per group.

Participants

A total of 250 participants were included in this cross-sectional, international study. Based on the participants' main language, 90 participants were assessed using the English version of the MoCA, 90 using the Hebrew version, and 70 using the Standard Arabic version. The MoCA has been officially translated and validated in both Hebrew and Standard Arabic[2,48,56]. The Hebrew version was standardized in Israel and is widely used in clinical and research contexts. The Arabic version has been validated in several Arabic-speaking countries, including Egypt and Saudi Arabia[56,57], and has shown good psychometric properties.

The YA were 18–30 years old. OA were above 50 years old. The English and Hebrew-speaking cohorts each included 30 YA, 30 OA, and 30 PwP. The Arabic-speaking cohort included 30 YA, 30 OA, and 10 PwP. We compared the three language cohorts within each participant group in terms of age and education. For age, we found no significant differences between languages within OA ($F(2.0, 41.4) = 0.63$, $p = 0.536$), but a significant effect was found within YA (($F(2.0, 56.2) = 9.44$, $p < 0.001$): Hebrew and Arabic ($t(57.9) = -2.75$, $p = 0.024$), Hebrew and English ($t(51.7) = -4.37$, $p < 0.001$), English and Arabic ($t(52.7) = 1.25$, $p = 0.648$)) and within the PwP (($F(2.0, 18.4) = 4.89$, $p = 0.020$): English and Arabic ($t(15.0) = -3.16$, $p = 0.019$), Hebrew and Arabic ($t(11.7) = -2.75$, $p = 0.054$), Hebrew and English ($t(20.5) = 1.05$, $p = 0.919$)). For years of education, no significant differences were observed within OA ($F(2.0, 41.2) = 2.00$, $p = 0.148$) and YA ($F(2.0, 55.4) = 0.07$, $p = 0.935$), but a significant effect was found within PwP ($F(2.0, 17.8) = 3.77$, $p = 0.043$): English and Arabic ($t(14.2) = -2.74$, $p = 0.047$), Hebrew and Arabic ($t(11.1) = -2.59$, $p = 0.075$), Hebrew and English ($t(19.6) = 0.62$, $p = 0.999$)). Given the potential effects of age and education on the MoCA score, these variables were included as covariates in all analyses to account for their potential confounding effects. See Table 1 for demographic and medical information of all groups.

PwP and OA participants were recruited through our Center for Accessible Neuropsychology (CAN) database. The database includes individuals who have been tested in CAN before or responded to online advertisements (e.g., PD-dedicated associations such as the "Israel Parkinson Association"). Participants resided in 126 different geographical locations: 29 different states in the USA and 87 cities, towns, or villages in Israel. See Fig. 3a, b for geographical marker maps of participants from the USA and Israel.

Inclusion criteria required a minimum of 18 years of age, normal or corrected vision, access to a computer and camera, and the ability to complete questionnaires online. Individuals with other neurological conditions (not PD), psychiatric conditions, learning disabilities, and severe visual or auditory impairments were excluded from the study. For the PwP group, participants who had undergone surgical intervention (e.g., Deep Brain Stimulation) were excluded, and all were on medications. This protocol was approved by the Tel Aviv University (TAU) Institutional Review Board Committee (#0005713-4). Informed consent was obtained from all individual participants included in the study.

Neurological and neuropsychological assessment

We followed the online neuropsychological testing published protocol (called iPONT: an International Protocol for Online Neuropsychological Testing)[2,3,10,58,59]. This protocol includes a script and procedure for participant recruitment through online platforms and for conducting online cognitive evaluations[22]. We specifically used the protocol for online participant recruitment and MoCA-VC administration, as it has been demonstrated to be a feasible and effective protocol for VC assessment, producing similar results obtained from in-person testing[2,10,22,46].

Participants who expressed interest were contacted via email to participate in a live interview with an experimenter. Video and audio issues were addressed before the start of each VC session to prevent interruptions. In the case of a video or audio issue that occurred during the meeting, it was resolved within a few minutes at the beginning of the session, or in rare cases (< 5%) led to the rescheduling of a session. After completing the informed a)

b)

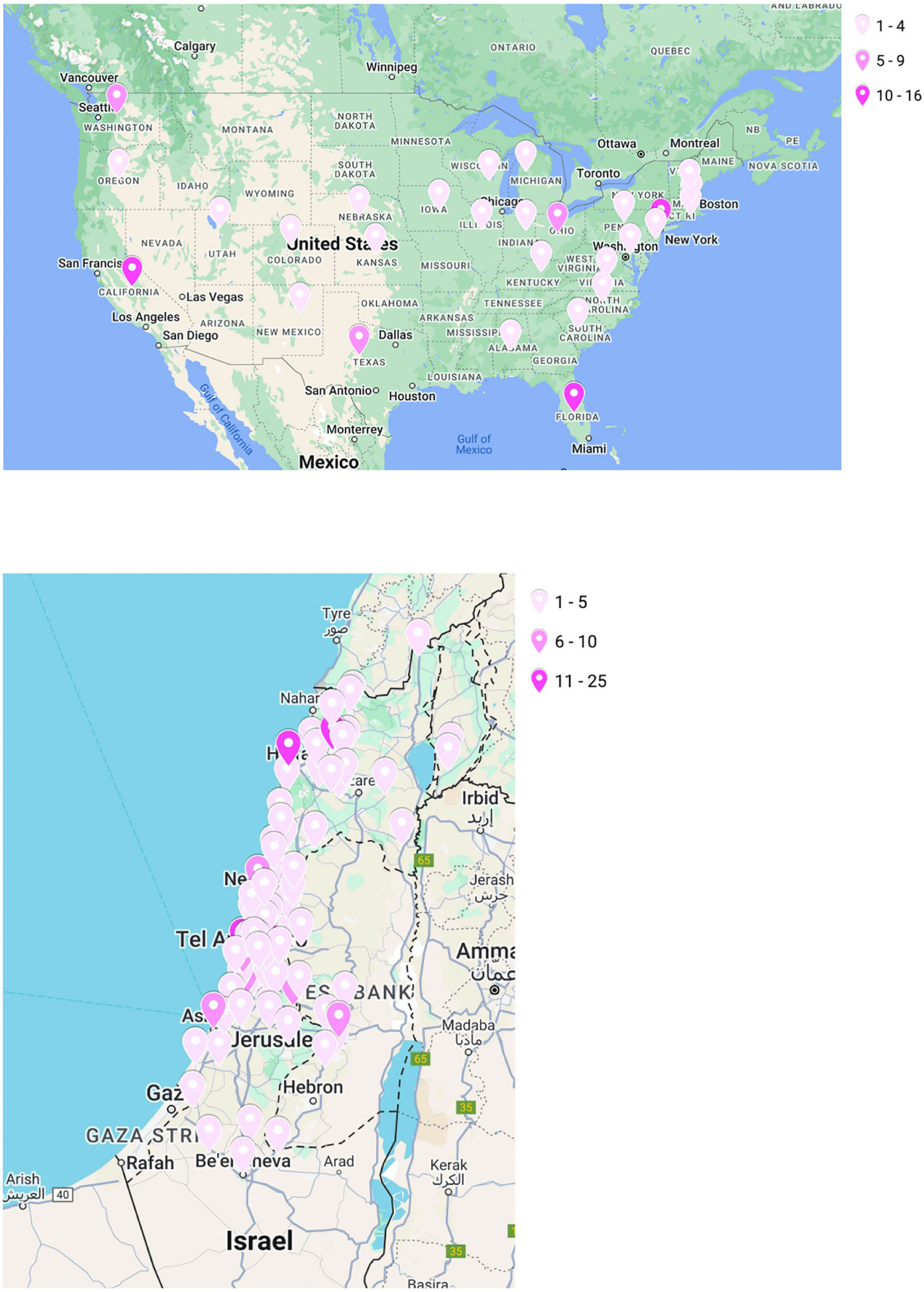

Fig. 3 | Geographic marker map of participant distribution. **a** Geographic marker map showing participants' locations across 29 U.S. states, displayed using Google Maps. **b** Geographic marker map displaying participants' locations across 87 cities, towns, and villages in Israel using Google Maps. The marker color indicates the number of participants per location: light pink = 1–4 participants, medium pink = 5–9 participants, dark pink = 10–16 participants. *Map data ©2025 Google, Imagery ©2025 TerraMetrics.*

consent form, the participant completed a demographic and medical questionnaire. Through the questionnaire, the experimenter obtained the participant's medical history, collecting information about age at diagnosis, medication, primary symptoms, genetic subtype, diet, other neurological or psychiatric conditions, and other relevant information pertaining to their health and lifestyle. Participants were then administered MoCA-VC (Version 8.1)[32]. The MoCA-VC took approximately 10 minutes to administer and complete[32].

In accordance with official MoCA administration guidelines, each participant was assessed by a single examiner. To ensure linguistic alignment, the examiner's primary language matched that of the participant, allowing the MoCA-VC to be administered in the participant's native language. Consequently, inter-rater reliability metrics such as the intraclass correlation coefficient (ICC) could not be computed. However, mean MoCA-VC scores across raters in each language were compared, and no significant differences were found (p >0.250), suggesting consistency in scoring. All raters completed the official MoCA training and certification.

PwP were additionally assessed using the Movement Disorder Society Unified Parkinson's Disease Rating Scale - Part III (MDS-UPDRS III) scale as well as the Hoehn & Yahr (H&Y) scale[60], which respectively measures motor severity and disease stage. All PwP participants had an H&Y score lower than four.

To ensure that there were no differences in disease severity between the three PwP groups, H&Y scores were compared across the different language groups. No significant differences were found (p >0.250; H&Y average score between 1 and 2). Since H&Y is a relatively non-sensitive measure (scale of 0–5), we also compared MDS-UPDRS III scores between the three groups. Again, no significant differences were found (p >0.250; range: 21.4 - 22.4). See Table 1.

Online modifications

Our MoCA-VC tests followed the official instructions provided on the MoCA website. Since the MoCA was administered online, several adjustments were made similar to previous studies[2–4,10]. First, participants were instructed through email before the VC session to have a pen or pencil and paper nearby. Six of the MoCA test items, from visuospatial to naming tasks, were presented on Google Slides via screen sharing on Zoom. For the Trail Making Test (TMT) section, participants were instructed to complete the task verbally[4]. For the drawing tests, participants were shown a cube on the screen with the label "Copy cube," and were instructed to replicate it. Additionally, participants were presented with the label "Draw clock," and were asked to draw a clock with a specific time given by the experiment. Afterward, they showed the drawings to the camera so that the experimenter could clearly see them. For the naming test, pictures of the naming stimuli were presented individually on the screen. For the orientation test, participants were asked to verbally report their location (city and place) whilst closing their eyes.

Data analysis

All statistical analyses were conducted using R software[61]. First, for confirmation, we evaluated the convergent validity of the MoCA-VC by comparing its scores to in-person MoCA scores for each language version using one-sample t tests[32,48,49]. To identify potential differences between groups in terms of age or years of education, we conducted ANOVA and t-tests with Bonferroni correction for multiple comparisons. To examine the effects of Group, Language, and their interaction on MoCA-VC scores, we conducted an ANCOVA test, considering age and years of education as potential covariates.

Data availability

All data needed to evaluate the conclusions in the paper are present in the paper. The datasets analyzed during the current study are not publicly available because they contain information that could compromise the privacy of the patients. Anonymized datasets are available from the corresponding authors on reasonable request.

Code availability

The code of this study is not openly available due to reasons of sensitivity and data privacy. The code used for data analysis is available from the corresponding author upon reasonable request. The analysis scripts were developed using open-source R packages.

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Author contributions

W.S. contributed to the conception, design, and analyses. T.G., S.K., R.G., and R.H. collected the data. All authors (T.G., A.L.A., E.V., S.K., R.G., R.H., V.M.L., and W.S.) helped to write the manuscript and contributed to the manuscript revision. All authors read and approved the final manuscript.

Competing interests

The authors declare no competing interests.

Additional information

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